PILOT PERFORMANCE CONTROLLING MULTIPLE ROVS IN TERMINAL AIRSPACE AND STRATEGIES FOR MANAGING THEM

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This paper is based on a demonstration of a distributed simulation conducted between the Flight Deck Display Research Laboratory (FDDRL) of NASA Ames Research Center and the Center for the Study of Advanced Aeronautic Technologies (CSAAT) at California State University, Long Beach. Simulated ROVs were flown in terminal airspace for the purpose of determining the feasibility of flying ROVs through commercial traffic. Pilots, with glass cockpit experience, were required to fly one or two ROVs in simulated airspace over water reservoirs near DFW airport, with the major goal of avoiding the approach traffic while patrolling Grapevine and nearby lakes. This paper will focus on pilot performance and strategies for controlling single versus multiple ROVs. Results showed that pilots had a difficult time patrolling the lake without losing separation from the approach traffic. However, their performance did improve after practice. Cooper-Harper workload ratings showed that pilots experienced higher workload when controlling two ROVs compared to one, especially in high traffic, which matches the performance data. Strategies for control of multiple ROVs are discussed.

INTRODUCTION

Advances in technology have enabled the use of remotely operated vehicles (ROVs) to perform tasks that are either too dangerous or simply mundane for human operators. Initially, the military used ROVs in a variety of roles: scout, decoy, surveillance, and transport (e.g., Draper & Ruff, 2000; Dixon & Wickens, 2004; Christner, 1991). Due to the rapid advancement in ROV technology, however, government and industry have identified many applications of ROVs that require ROV presence in the National Air Space (NAS). ROVs can potentially be used for commercial, civil, and homeland security applications. Homeland security applications include surveillance and reconnaissance, border and harbor patrols, and law enforcement (Access 5, 2005).

Currently, ROVs are permitted to operate only in restricted and special-use airspaces, in certain highly regulated and constrained instances, and in limited areas of normal domestic airspace (e.g., along the Texas-Mexico border; Federal Aviation Administration, 2004). In response to the rapid expansion of the intended uses of ROVs, many aerospace organizations have been examining the requirements for achieving the capability to operate ROVs safely, reliably, and routinely in the NAS. The Access 5 Program, for example, was undertaken to first identify and/or develop standards, regulations, and procedures for ROV routine access to high altitude (i.e., above 40,000 ft.) long endurance operations. Eventually, standards and procedures would be extended to lower altitudes, and, ultimately, to any airport capable of supporting ROVs (Access 5, 2006). In the demonstration reported here, we simulated ROVs flying in terminal airspace, as a first attempt in identifying performance and operational issues that must be resolved before ROVs can routinely obtain “file and fly” access to the NAS.

Normally, ROVs are managed by a minimum of two crewmembers: air vehicle operator (AVO) and payload specialist. However, the ultimately goal is to reduce the number of crewmembers required to a single operator controlling multiple ROVs. Although research has demonstrated that a single pilot can control multiple ROVs, these demonstrations were limited to special airspace environments with little or no commercial traffic and highly reliable automated aids (see e.g., McCarely& Wickens, 2005; Nelson et al., 2005; Ruff et al., 2004). To date, no one has considered the implications of multiple ROVs controlled by a single operator in commercial terminal airspace. Therefore, in our simulation pilots flew either one or two ROVs simultaneously through approach traffic at Dallas Fort Worth (DFW) airport.

METHOD

Participants

Four pilots participated in the simulation over a 5-day period. Three of the pilots were rated *Commercial ATP*, and one was *CF II*. Two pilots were rated for 767 jets and 2 Turboprop planes. They had 100 – 6,000 hours of glass cockpit experience and 4,000 – 18,000 total hours of flight experience. Pilots were paid either $25/hr for participation at NASA Ames, and $60/hr for their participation in Long Beach (to cover travel expenses.)

Apparatus

The simulation was conducted over a network, using flight simulation software that was distributed between FDDRL and CSAAT and connected over the internet. The system consists of four main components (see Strybel et al., 2006, for details): the Multi-aircraft Control System (MACS); Cockpit Situation Display (CSD); Flight Simulation Voice Over Internet Protocol (also known as DagVoice); and Aeronautical Datalink and Radar Simulator (ADRS).

In the scenario, three main streams of inbound traffic occupied the DFW air space (see Figure 1). Stream A entered the approach air space from downwind and then merged with Stream B, which entered the approach airspace north of DFW onto runway 18-right (18R). Stream C traffic arrived north of DFW landing on 13-right. Stream B traffic crossed the GIBBI fix at 4,000 ft and Stream A crossed GIBBI at 3,000 ft. ROV mission objectives were to survey along Grapevine Lake starting from the southeast end and continuing along the lake to the northwest end before surveying Eagle Mountain and Benbrook lakes. At all times, the ROV operators were to maintain separation from the previously described inbound traffic arriving in Streams A, B, and C. Note that all approach traffic was automated (no human control during the simulation). The role of ATC was scripted in that ATC only acknowledged ROV flight plan changes, but did not respond to its appropriateness (i.e., approve or disapprove the change) or provide alternate flight plans. ROV pilots were provided with the specific rules of the road (see Battiste et al., 2006, for more details).

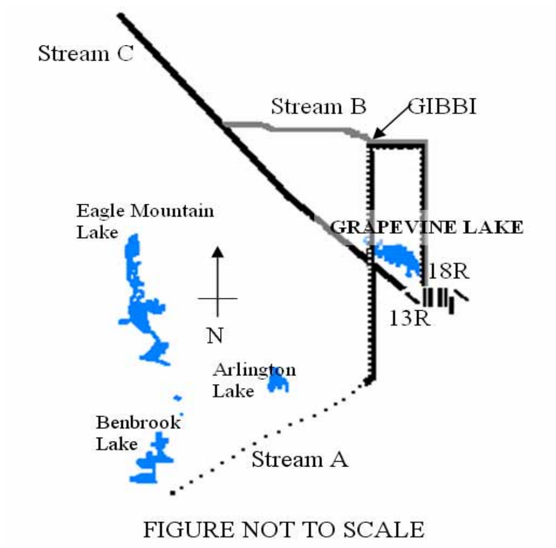

Figure 1. Map of lakes near DFW and streams of approach traffic into the DFW airport.

Procedure

Two pilots flew ROVs in the simulation at CSAAT and two flew at FDDRL. Traffic was generated with MACS software located at FDDRL. All pilots were trained on the basic functionality of the software and flight plan during the first day of the study at NASA Ames Research Center. Two researchers from CSAAT were involved in the training phase. Immediately following the training session, the two CSAAT researchers and two pilots flew to Long Beach. The following 4 days were spent running variations of the basic scenario. The variations consisted of the number of ROVs controlled by a pilot (1 vs. 2), traffic density (heavy vs. light), and ROV formation (staggered vs. grouped, see Figure 2). The formation variable is considered to be more critical for the multiple ROV condition since it determines the separation of the two ROVs controlled by each operator. In addition, a pilot controlled either the leading or the trailing ROV.

The pilot interface consisted of a stripped-down, simulated Boeing 777 cockpit (MCP, FMS, PFD, landing gear status, etc.) that included a window with the call signs of all vehicles in the scenario as well as the aircraft (1 or 2) under the pilot's control (see Figure 3). The call sign of the active vehicle was highlighted in yellow. The pilot switched control simply by clicking on the call sign of another vehicle in the window, thus changing the color from white to yellow.

Figure 2. Illustration of the formation variable.

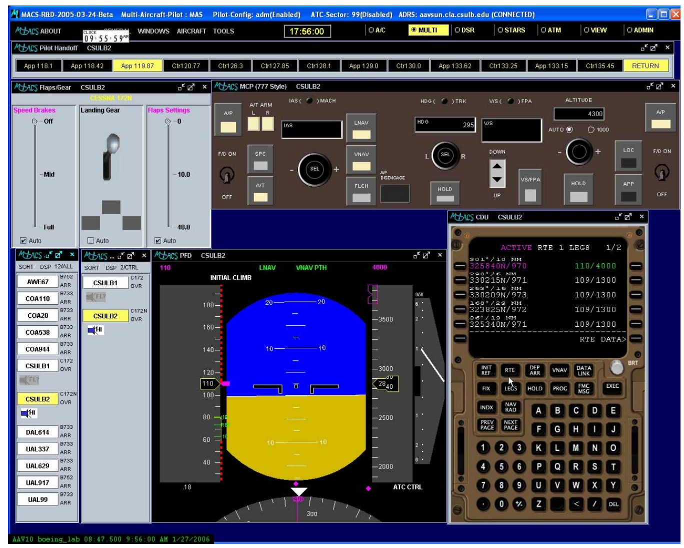

Figure 3. Display of pilot cockpit interface.

The pilot's cockpit also included a 4-D CSD that showed a 3-D view of the traffic in the vicinity of the controlled vehicle (see Figure 4), highlighted conflicts, and allowed flight plan modifications by pointing and clicking. Conflicts were shown on the CSD by changing the colors of the active vehicle (i.e., under pilot control) and intruding vehicle to yellow. Conflicts levels (Levels 1, 2, and 3) were signaled by a change in brightness. Level 1, which indicated 3-7 minutes to LOS was in pale yellow; Level 2, which indicated 2-3 minutes to LOS was in amber; Level 3, which indicated less than 2 minutes to LOS was amber with a halo.

Six sessions were run each day over four days, making a total of 24 simulation runs, with each run lasting approximately 25-30 minutes. Dependent measures were recorded from simulation data-logging software and from video and screen-capture software. Measures of system performance collected included number of conflicts, severity (level) of conflicts, and parameters affecting mission success. Overall pilot subjective and performance measures included workload, amount of lake covered, strategies for resolving conflicts, and ratings of mission success. Measures related to the control of multiple ROVs included the number of times the pilot switched from operating one ROV to another and the amount of time spent controlling each ROV.

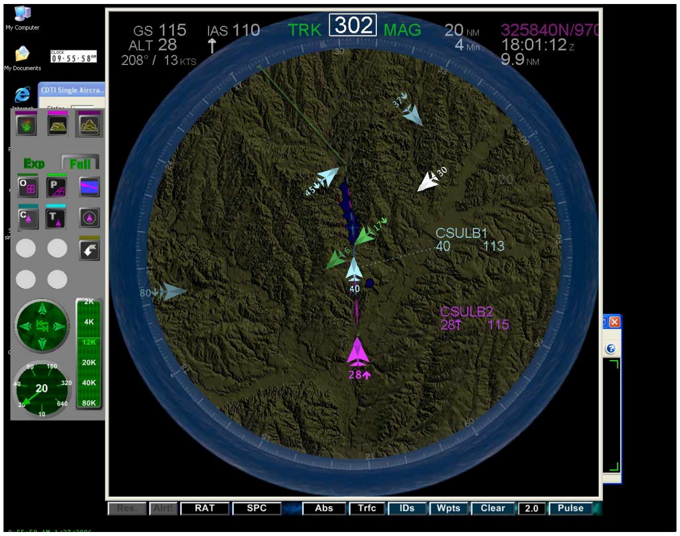

Figure 4. Illustration of the 4-D CSD interface.

RESULTS AND DISCUSSION

As the distributed simulation was more demonstration than formal experiment, and only four pilots participated in the simulation, the results are more descriptive than inferential in nature. Nevertheless, some interesting result patterns emerged from these data. The formation variable was only examined in the conditions in which pilots controlled multiple ROVs.

Number of Conflicts and Loss of Separation

Total Conflicts. Analysis of the data log files showed that, in the 24 trial runs, the ROVs were in conflict (all levels) a total of 569 times. The majority of the conflicts occurred when the pilots were controlling two ROVs (N = 419) than when they were controlling a single ROV (261 conflicts). Although the mean number of conflicts of 24 per run seems high (6 per ROV operator), it reflects the fact that the ROVs were in close proximity to the approach traffic throughout the run, and when an ROV was in conflict, it was usually in conflict with more than one other aircraft (range = 1 to 5).

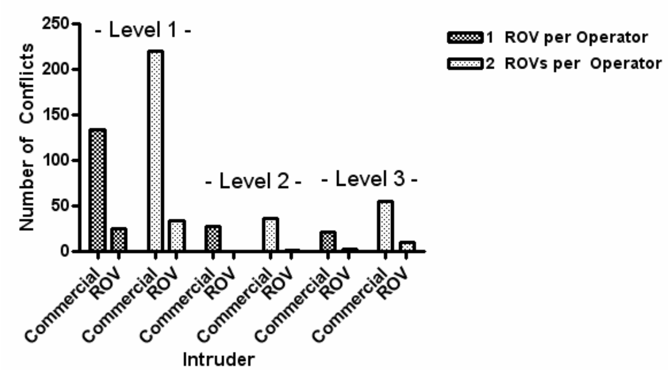

Figure 5. Number of conflicts across pilots over the four days of simulation at each alert level when the conflict began, as a function of controlling a single or multiple ROVs and intruder type.

Figure 5 shows the initial conflict level with commercial and ROV aircraft when the pilot was controlling one or two ROVs. Across all levels of conflicts, more alerts occurred when pilots controlled two ROVs compared to one ROV. The majority of conflicts began as level 1 meaning that pilots were warned that, if they continued on their path, they would lose separation requirements within 3-7 minutes. At each level, there were more conflicts with commercial (approach) traffic than with other ROVs, because of the greater number of commercial aircraft in the vicinity.

Resolving conflicts in this scenario was not easy: As shown in Figure 6, roughly half of the Level 1 conflict alerts increased to Level 3, meaning that pilots had less than 2 minutes before losing separation, and some Level 3 alerts eventually resulted in LOS. Moreover, Level 3 conflicts and LOSs were more common when pilots flew two ROVs simultaneously than when they only flew one ROV.

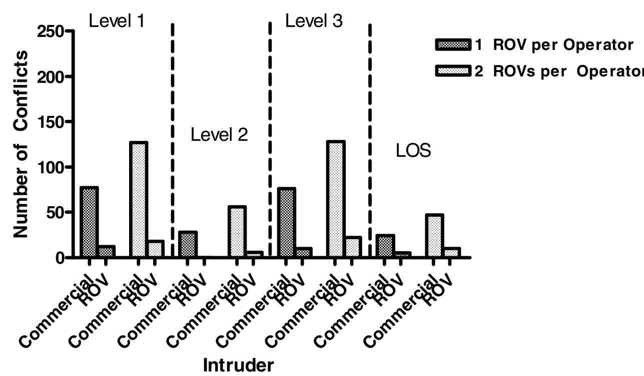

Figure 6. Highest alert level for each conflict as a function of controlling a single or multiple ROVs and intruder type.

With light traffic, Level 3 conflicts occurred 27 times when controlling multiple ROVs and 20 times when controlling a single ROV. This finding suggests that, although the task is difficult, it may be possible to control multiple ROVs in light traffic. For heavy traffic, the numbers were much higher, with 95 conflicts when controlling multiple ROVs and 46 conflicts when controlling a single ROV. Moreover, for multiple control of ROVs, there was little difference in the number of Level 3 conflicts for group and staggered formation (N = 29 vs. 32 conflicts, respectively); only traffic level had a large effect (N = 14 vs. 48 for light and heavy traffic level, respectively).

Across the 24 trial runs, the ROVs lost separation with another aircraft a total of 57 times when pilots were controlling multiple ROVs, and only 29 times when controlling a single ROV. With light traffic, pilots lost separation 16 times when controlling multiple ROVs and 7 times when controlling a single ROV. For heavy traffic, the numbers were much higher with LOS occurring 41 times when pilots controlled multiple ROVs and 22 times when they controlled a single ROV. Moreover, for multiple control of ROVs, there was little difference in the number of LOS for the different formations under light traffic (M = 7 vs. 9 for staggered versus grouped formation) and heavy traffic (M = 24 vs. 17 for staggered versus grouped formation).

Resolved Conflicts

Pilots were considered to be able to successfully resolve any conflict if they were able to do it 2 minutes before LOS.

Percentage of conflicts resolved. Overall, the pilots were able to resolve 72% of all conflicts, with more successful resolutions when pilots controlled a single ROV (M = 89%) than multiple ROVs (M = 56%). With control of a single ROV, pilots were able to resolve 85% of conflicts with light traffic, but only 64% with heavy traffic. With of control of multiple ROVs, pilots were able to resolve 80% of the conflicts in light traffic under the staggered formation, but only 69% under grouped formation. With high traffic and control of multiple ROVs, 62% of the conflicts were resolved for both types of formation.

Time to conflict resolution. On average, the pilots took 93 seconds to resolve all conflicts. Although pilots experienced more conflicts with commercial aircraft, resolving conflicts with other ROVs took longer, as shown in Figure 6. This increase may be due to the fact that the ROVs were traveling at slower speeds than commercial aircraft, allowing pilots more time to resolve the conflict. Note, however, that the effect of number of ROVs, traffic density and intruder type appear to be additive. For example, there was no change in the difference in resolution times between commercial and ROV intruders, and between single and multiple ROV control as a function of traffic density. In fact, traffic density had little effect on the time to resolve conflicts. With multiple control of ROVs, pilots were able to resolve conflicts much faster with grouped formation (M = 90 seconds) than for staggered formation (M = 141 seconds). This finding may reflect the fact that when the two ROVs are in close proximity, the pilot had better situational awareness for activity affecting both ROVs simultaneously.

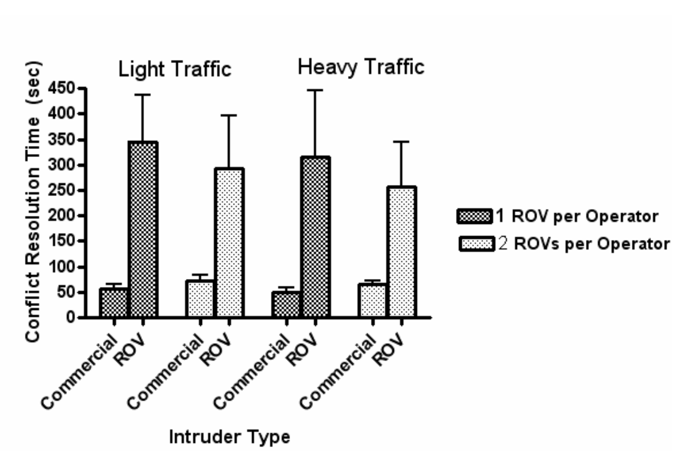

Figure 7. Mean conflict resolution time in light and heavy traffic as a function of intruder type and control of ROV.

Subjective Workload Assessment

Cooper-Harper (CH) ratings were higher when controlling two ROVs (M = 3.6) than when controlling a single ROV (M = 2.8). A CH workload rating of 3.6 approaches a critical value of 4, suggesting that workload should be reduced. Pilot workload ratings for control of multiple ROVs were reduced more with practice, with the workload ratings on day four being rated as "fair" (CH = 3) for both conditions. The formation of the four ROVs had little effect on perceived workload. However, traffic density produced higher workload ratings on average (heavy traffic = 4.3; light traffic = 2.4). The CH ratings for the heavy traffic condition suggest that workload may be too high, and needs amelioration.

Individual Differences and Effects of Practice

The performance of each pilot was also examined to determine whether there were individual differences in the control of single versus multiple ROVs in these scenarios. Table 1 shows the total number of Level 3 conflicts encountered by pilots with control of a single or multiple ROVs. Table 2 shows how many conflicts (all levels) that the pilots were able to resolve at least 2 minutes prior to LOS.

There were clear differences in pilots' ability to complete the mission. As can be seen from these data, Pilot 4 had the most difficult time with the task. However, it should be noted that Pilot 4 reported being unfamiliar with the Boeing 777 MCP, and indicated having difficulties with the interface since the first day of the simulation. Pilot 2 clearly showed the best performance. Individual differences between pilots could be minimized by providing more training with the interface. In the debriefing session, all pilots indicated that they could have benefit from more training than what was given during the first day of the simulation.

Pilots tended to show improvement in their performance from the first half to second half of the simulation period (see Tables 1 and 2). The severity of conflicts also changed with practice. Overall more level 3 conflicts occurred on the first day of simulation compared with the remaining days. For the first two days of the simulation the mean conflict level was 2.1 per simulation run for heavy traffic, and 1.8 for light traffic. For the last two days, the mean conflict level was below Level 2 for light and heavy traffic (means = 1.9 and 1.6, respectively), with greater improvements observed in the light traffic conditions. These results are consistent with pilot verbal reports indicating that their performance improved over the four day simulation period.

Single- LOS within 2 minutes									
	Day 1		Day 2		Day 3		Day 4		
	Light	Heavy	Light	Heavy	Light	Heavy	Light	Heavy	
Pilot									**Total**
1	0	1	4	6	1	4	2	0	**18**
2	2	0	0	1	2	1	0	2	**8**
3	8	7	2	4	2	8	5	7	**43**
4	16	9	7	9	6	5	6	5	**63**

Multiple- LOS within 2 minutes									
	First 2 Days				Last 2 Days				
	Light		Heavy		Light		Heavy		
	Staggered	Grouped	Staggered	Grouped	Staggered	Grouped	Staggered	Grouped	
Pilot									**Total**
1	2	1	8	8	3	3	8	6	**33**
2	5	4	5	13	4	3	6	7	**40**
3	7	6	15	9	7	3	10	13	**57**
4	11	7	11	12	6	5	9	7	**61**

Table 1. Number of Level 3 conflicts for individual pilots with control of a single or multiple ROVs.

Single									
	Day 1		Day 2		Day 3		Day 4		
	Light	Heavy	Light	Heavy	Light	Heavy	Light	Heavy	
Pilot									**Total**
1	3	6	4	6	4	5	2	1	**31**
2	2	1	0	1	2	1	1	6	**14**
3	8	13	2	11	3	9	7	7	**60**
4	22	15	8	15	6	9	8	10	**93**

Multiple									
	First 2 Days				Last 2 Days				
	Light		Heavy		Light		Heavy		
	Staggered	Grouped	Staggered	Grouped	Staggered	Grouped	Staggered	Grouped	
Pilot									**Total**
1	2	5	10	14	5	3	12	10	**61**
2	5	4	9	14	4	3	7	9	**55**
3	9	10	19	15	7	6	15	17	**98**
4	12	11	24	33	11	6	20	10	**127**

Table 2. Number of resolved conflicts (all levels) for individual pilots with control of a single or multiple ROVs.

Measures of Multiple ROV control

In the multiple ROV conditions, pilots switched between ROVs to monitor the flight plan and ensure that both ROVS were able to complete the mission without losing separation with other aircraft. On average, more time was spent flying the lead ROV in the pair (Mean difference = 10 sec.). Traffic density had little effect on the number of times pilots switched between ROVs (28 vs. 26 switches for light vs. heavy traffic respectively.) However, traffic density interacted with ROV formation. For light traffic, more switching occurred with grouped ROVs than staggered ROVs (33 vs. 20 switches respectively). Because the pilots switched between the planes more often in grouped formation, it can account for why the conflict resolution time is shorter for this formation compared to the staggered formation. In other words, with the grouped formation, pilots updated the status of the two ROVs more often, which may improve the pilot's understanding of the environment and reduces the time needed for conflict resolution. However, this difference was not present in heavy traffic, as the mean number of switches was equivalent (26 vs. 25 switches). Less switching may have occurred with heavy traffic because more conflicts of higher severity occurred in that condition. Hence, the pilots needed to spend more time resolving the conflicts rather than monitoring the two ROVs.

SUMMARY AND CONCLUSIONS

These preliminary findings indicate that flying multiple ROVs and avoiding traffic in busy terminal airspace is difficult. With control of multiple ROVs, more conflicts occurred, the conflicts were more severe, and workload was higher. Even when flying a single ROV in terminal airspace, pilots experienced difficulties. It is also important to note that the difficulties were experienced even though there was no payload mission involved in the scenarios (i.e., photographing the lake). Whereas flying ROVs without LOS is possible at high altitudes (e.g., Access 5, 2006), the ROV operators may experience much difficulty getting to the high altitude if the flight plan involves terminal airspace or heavy commercial traffic.

At the end of the week, one pilot was able to fly multiple ROVs through terminal airspace without losing separation with another aircraft. However, this pilot still experienced Level 3 conflicts during these runs. The fact that this pilot was successful in completing the mission without any LOS on the last day suggests that it may be possible with extensive training.

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